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GLOVEBOX FACILITY FOR PYROCHEMICAL RESEARCH AND DEVELOPMENT WORK WITH PLUTONIUM-238

by

J. Fischer

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J. Fischer

Chemical Engineering Division

May 1969

PREFACE

Many of the programs in the Chemical Engineering Division at Argonne National Laboratory have involved investigations into pyrochemical processes for the separation and purification of uranium and plutonium from nuclear fuels and materials. These processes use liquid metals and molten salts as process solvents. The glovebox facility described in this report was constructed to allow experimental pyrochemical work to be performed with materials containing plutonium-238 in a high-purity, helium-atmosphere enclosure, which is at a negative pressure with respect to the surrounding working area. The author hopes that the information provided here will be useful to other workers in the design of similar facilities. Although this report does not provide all the details of construction of the facility, the appendix and the works referenced should be helpful in obtaining further information.

TABLE OF CONTENTS

TABLE OF CONTENTS

LIST OF FIGURES

GLOVEBOX FACILITY FOR PYROCHEMICAL RESEARCH AND DEVELOPMENT WORK WITH PLUTONIUM-238

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ABSTRACT

A detailed description of a facility for conducting pyrochemical research and development work with plutonium-238 is given. The facility comprises a negative-pressure glovebox containing both a high-purity helium and an air-atmosphere section for experimental work, and an air-atmosphere glovebox for analytical work. The general capabilities of the facility are discussed, and the gloveboxes and associated equipment are described in detail. Equipment items include furnaces, gloves, utilities, cooling-water and vacuum systems, and instrumentation for temperature measurement and for atmosphere purification and control.

1. INTRODUCTION

The Plutonium-238 Research and Development Facility was built to provide the necessary gloveboxes and equipment for pyrochemical processing experiments with nuclear materials containing plutonium-238. In these experiments, plutonium-238 is handled in the form of a metal or an oxide, alone or in conjunction with molten halide salts and liquid metals such as zinc, magnesium, or cadmium.

Significant amounts of alpha activity and gamma radiation are associated with plutonium-238. For example, the alpha activity is approximately 300 times that of plutonium-239. Therefore, more stringent precautions are required than those normally used with plutonium-239. Most of the gamma radiation associated with plutonium-238 is of low energy and is easily shielded by equipment such as furnaces, furnace tubes, and the structure of the gloveboxes. The prime means of limiting exposure of operating personnel to neutrons (resulting from α-n reactions) and gamma rays in the facility is separation from the source. Lucite and water neutron shielding are provided where necessary, and radiation monitoring devices are used.

The facility consists of an operating area containing two gloveboxes and their associated equipment and an isolation room. An effort was made in the design of the facility to minimize the need for movements of material and personnel in and out of the facility during routine operations. Every effort has been made to restrict contamination from plutonium to the vessels in which it is processed.

The equipment used in constructing the facility is, in general, commercially available. The source of most of the major equipment items is given in the appendix of this report. The items are identified by superscript numbers throughout the report, and these numbers are keyed to entries in the appendix.

2. DESCRIPTION OF FACILITY

2.1 Layout of Laboratory and Isolation Room

The Plutonium-238 Research and Development Facility consists of a laboratory having an area of 560 ft^2 and an adjoining isolation room having an area of 70 ft^2. Figure 1 is a floor plan of the facility. Two gloveboxes are housed in the larger or experimental area. The larger glovebox (glovebox A) is divided into two sections. One section has a volume of 343 ft^3 and contains a high-purity helium atmosphere. The adjoining section has a volume of 86 ft^3 and contains an air atmosphere. The smaller glovebox (glovebox B), also referred to as the analytical box, has a volume of 258 ft^3 and contains an air atmosphere. Glovebox B is connected to the air section of glovebox A by a transfer tunnel.* Figure 2 is a view of the facility between gloveboxes A and B. The transfer tunnel is the rectangular duct directly above the head of the operator near the wall in Fig. 2.

Access to the experimental area is obtained through the isolation room, which is maintained at an atmospheric pressure that is lower than that of the corridor and higher than that of the experimental area. The isolation room provides an area for changing protective clothing and for surveying personnel and materials entering or leaving the experimental area.

2.2 Glovebox A

2.2.1 Helium Section

The helium section of glovebox A is used for experimental pyrochemical work requiring an inert atmosphere and contains furnaces, furnace vessels, and associated equipment. The experiments performed in this section use liquid metals and molten salts to produce purified plutonium-238. In the experiments, the plutonium-238 is in the form of ^{238}Pu oxide or metal, alone or alloyed with mixtures of magnesium, cadmium, or zinc.

The helium section contains three furnaces (as shown in Fig. 1), two of which are resistance heated and are mounted in a 33 by 33 by 32-in.-deep rectangular well in the floor of the glovebox. The third furnace is an induction-heated tilting furnace mounted above the floor of the glovebox.

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*Further information on the design of the gloveboxes, which were built to a Chemical Engineering Division standard, can be obtained in a paper by R. F. Malecha et al., "Low Cost Gloveboxes," published in the Proceedings of the 8th Conference on Hot Laboratories and Equipment of the Americal Nuclear Society, TID-7599 (1960).

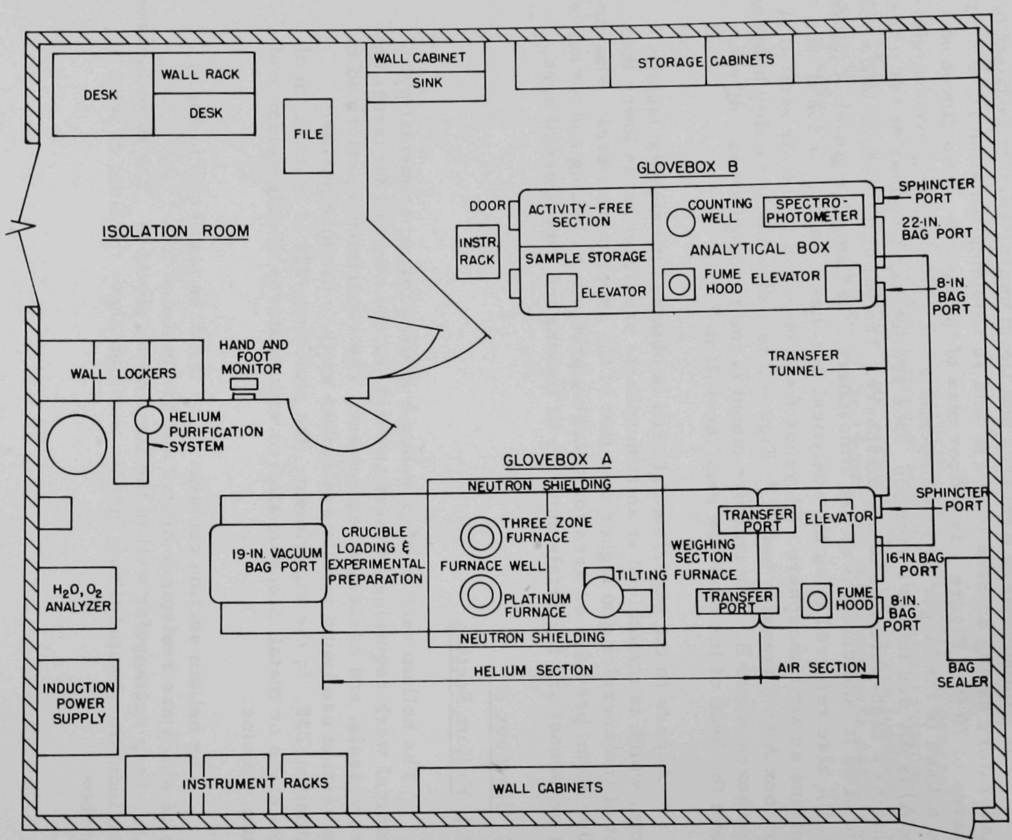

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Fig. 1. Floor Plan of Plutonium-238 Facility

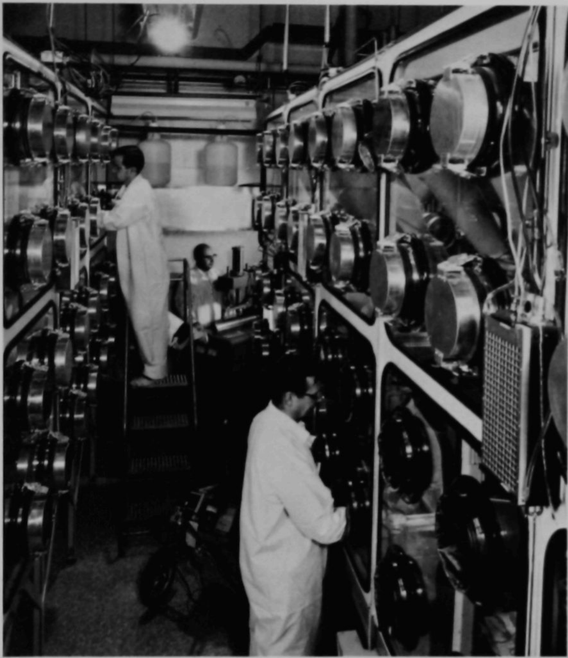

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Fig. 2. Experimental Area

Special precautions are taken to limit exposure of the operating personnel to neutrons in the area of the furnaces. In the furnaces, ^{238}Pu metal in contact with magnesium produces a higher level of neutron activity than $^{238}PuO_2$. Three-inch-thick Lucite windows are placed over the regular glovebox windows in this area to moderate fast neutrons, as shown in Fig. 3. Figure 4 is a view of three of the four modules of the helium section of glovebox A with the Lucite windows removed. A 6-in.-thick tank of water is visible to the right of the operator in Fig. 4. This tank and another identical to it on the opposite side of the box are used to moderate neutron activity originating from the two resistance furnaces mounted in the well in the floor of the glovebox. The rectangular grills seen next to the windows in Figs. 3 and 4 are alpha detection monitors with which an operator can check his hands after withdrawing them from the gloves. The black sphere to the operator's left in Fig. 4 is a portable neutron monitor,[1*] which can be moved to the area where the operator is working. A neutron air monitor[2] is also placed in the vicinity of the operators.

*Note that superscript numbers refer to items listed in the appendix.

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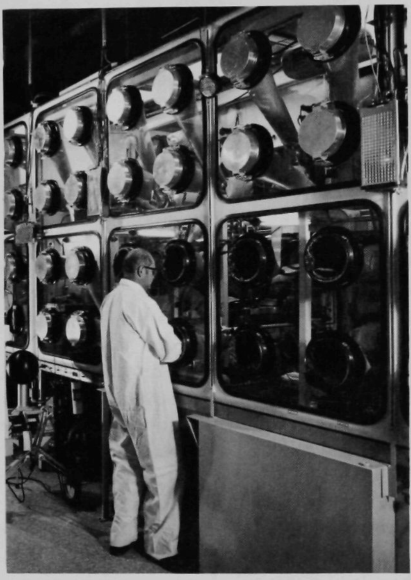
Fig. 3. Lucite Shielding Windows on Helium Section of Glovebox A



308-1546

Fig. 4. Helium Section with Shielding Windows Removed

A hoist and simple manipulators are provided in the helium section to allow movement of plutonium-238 in secondary containers and thereby prevent the spread of activity to the gloves, painted surfaces, exteriors of primary containers, or tools within the glovebox.

2.2.1.1. Work Areas

2.2.1.1.1. Experimental and Sample Preparation Area. A space is provided above the two resistance-heated furnaces, which are mounted in a well in the glovebox floor (as shown in Fig. 1), for sampling the melts within the furnaces and for other operations such as loading and unloading the furnaces and furnace maintenance. A movable shelf, half the width of the glovebox, is mounted above the furnaces and is used for storing auxiliary equipment such as a vacuum cleaner.

A small lathe[3] is located below the tilting furnace in a stainless steel pan provided with a Lucite cover for dust control. The lathe is used for preparing samples taken of the melts in the furnaces. Figure 5 shows a sample tube in the lathe with the Lucite cover in place. A small cutoff wheel, next to the lathe, is used to remove the empty portion of sample tubes before their contents are dissolved. The cutoff wheel also is provided with a Lucite cover and mounted in a stainless steel pan. A Wig-L-Bug laboratory grinder[4] housed in a steel guard is located between a tilting furnace and the weighing area. The grinder, which is used to pulverize salt samples before weighing and analysis, may be lifted by hoist for storage or may be located and used on a shelf above the weighing area.

308-1532

Fig. 5. Lathe for Sample Preparation

2.2.1.1.2. <u>Weighing Area</u>. Three balances are located at the end of the helium section closest to the air section. The balances include a 3-kg-capacity torsion balance,[5] a 120-g-capacity torsion balance,[6] and an analytical balance.[7] Figure 6 shows one of the operators using the analytical balance.

308-1544

Fig. 6. Operator Using Analytical Balance

2.2.1.1.3. Storage Area. An adjustable shelf is located above the weighing area (see Fig. 1) for storage of furnace parts and other heavy equipment. Equipment may be moved to and from this shelf with an overhead hoist. Tools are stored in a large, rotating multishelf storage bin, located near the large (19-in.) vacuum bag port (see Fig. 1).

2.2.1.2. Helium Purification and Atmosphere Control. The helium section of glovebox A is designed to contain pure, dry helium at a pressure of 0.8 in. of H_2O less than the atmospheric pressure in the surrounding room. The water and oxygen levels in the helium atmosphere are maintained at less than 2 and 5 ppm, respectively, by the helium purification system.* The components of the purification system include a dryer, an adsorber, and a circulating blower. Figure 7 is a schematic diagram of the purification system, and Fig. 8 is a photograph of the system.

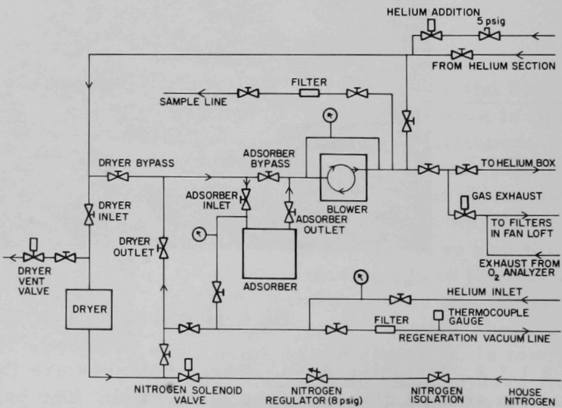


Fig. 7

Schematic Diagram of Helium Purification System

308-1930

*The helium purification system was designed according to information provided by J. Ludlow of the Chemical Engineering Division. More detailed information on the development of this system is available in a paper by J. Ludlow et al., "High Purity Helium Atmosphere for Plutonium Research," published in the Proceedings of the 14th Conference on Remote Systems Technology, Americal Nuclear Society (1966).

308-1547

Fig. 8. Helium Purification System

The dryer (tank covered with aluminum foil in Fig. 8) contains Molecular Sieves, which remove water. The adsorber (large tank in center of Fig. 8) consists of a liquid-nitrogen-cooled charcoal trap, which further removes water and carbon dioxide and effectively adsorbs oxygen and nitrogen cryogenically.

A blower (housed in the dark tank near the operator's head in Fig. 8) circulates gas from the helium section of glovebox A through the purification system and through two AEC-type absolute filters, mounted in parallel, before the gas enters the top of one end of the helium section of the glovebox. Gas is removed from the helium section through two parallel AEC filters, located below the entry filters, and is then returned to the purification system. Helium that is added to the system is introduced at a point between the exit filters and the purification system so that it is purified before entering the glovebox.

The Molecular Sieves in the dryer are usually regenerated biweekly by passing nitrogen through them in reverse flow while they are heated. The condensed and adsorbed gases are removed from the adsorber by pumping on the adsorber with a high-capacity vacuum pump while heating the walls of the adsorber to approximately 150°C.

Four instruments are used to monitor the water and oxygen levels of the glovebox atmosphere and the helium leaving the purification system. The purified gas at the outlet of the blower is sampled and analyzed with a Meeco oxygen analyzer[9] and water analyzer[10] to determine the performance of the purification system. The water content at various locations inside the helium section is analyzed with a Panametrics hygrometer,[11] and the oxygen level is monitored with a Thermo-Lab oxygen analyzer.[12] A valving arrangement permits isolation of the purification system from the glovebox so that the effectiveness of the dryer and adsorber can be determined. The levels of oxygen and water in the exit gas from the purification system are monitored to determine the need for regeneration of the dryer and adsorber.

Several safety features have been included in the atmosphere control system of the helium section. The glovebox pressure, which during normal operation can vary from 0.4 in. H_2O less than room pressure to 0.8 in. H_2O less than room pressure, is monitored by a differential pressure gauge.[13] If the glovebox pressure rises above 0.4 in. H_2O negative, as determined by a differential pressure sensor,[14] a 3/4-in. solenoid valve in a line leading from the helium section to the laboratory exhaust duct opens automatically until the pressure in the helium section drops to about 0.8 in. H_2O negative. A high-pressure alarm is set to sound if the pressure should reach 0.2 in. H_2O negative. If the pressure in the helium section increases to 3.0 in. H_2O positive, a bubbler filled with silicone oil will release the excess pressure to the laboratory exhaust duct.

A low-pressure alarm will sound if the pressure in the helium section reaches 1.2 in. H_2O negative. If the pressure drops to 2.5 in. H_2O negative, all vacuum pumps connected to equipment in the helium section or to the purification system are automatically shut off and must be restarted manually. If the pressure in the helium section decreases to 4.0 in. H_2O less than room pressure, the bubbler will allow room air to be drawn into the glovebox to prevent damage to the system. A solenoid valve in the helium supply to the system opens at 0.8 in. H_2O negative. The addition of helium from the helium manifold is slow, because the supply pressure is set at 5 psig. Therefore, if the solenoid valve in the supply line failed to close, the bubbler and exhaust system could handle the excess pressure.

2.2.1.3. Entry and Egress from Helium Section. Three ports in the helium section allow entry and egress of material from the section without adversely affecting the purity of the atmosphere in the helium section.

A large cylindrical vacuum bag port, 19 in. in diameter by 40 in. long, is attached to a gasketed surface at one end of glovebox A. This port, seen at the right in Fig. 9, is shown schematically in the upper portion of Fig. 10. The port allows material to be moved in and out of the helium section from the operating area outside the glovebox and is provided with a means of bagging the materials transferred in sealed plastic pouches to prevent the spread of contamination. The port is used only for large equipment items and therefore is used infrequently. An alpha detector probe is located inside the outer door of the port to determine if any alpha activity has gotten beyond the bag before the door is opened during transfer operations.

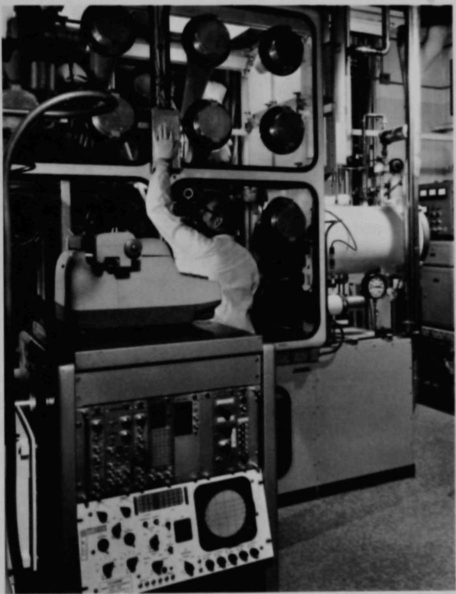


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Fig. 9. Helium-section End of Glovebox A

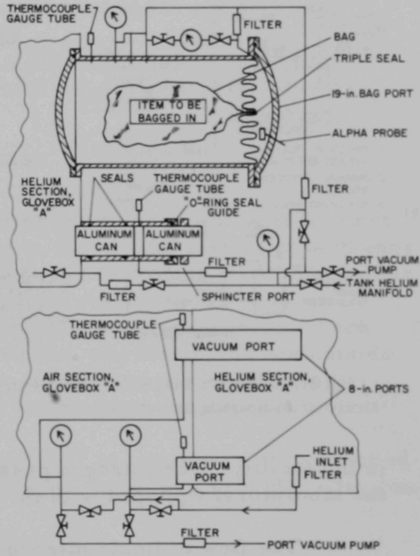


Fig. 10. Schematic Diagram of Vacuum and Sphincter Ports

A sphincter port is provided in the end of the glovebox next to the 19-in.-diam port. This unit, which also is evacuated during transfers, allows rapid transfer of small items into the helium section. A schematic diagram of this port is also shown in the upper portion of Fig. 10. The port employs a double O-ring seal and close-fitting sphincter cans to provide the one-way transfers.

Two smaller ports, both 8 in. in diameter, extend from the air section of glovebox A through the partition into the helium section. A schematic drawing of these two ports is shown in the lower portion of Fig. 10. The larger of the two ports is 30 in. long and is located in the upper portion of the glovebox. This port is used to transfer long items such as thermocouples, furnace tube liners, and long tools. The shorter port, which is 10 in. long, is located near the floor of the glovebox on the opposite side of the glovebox from the long port. There is no need for bagging operations with these smaller ports, but both are evacuated and filled with helium filtered through a 1- to 5-micron filter during transfer operations to protect the atmosphere in the helium section.

2.2.1.4. Liquid-nitrogen Dispensing System. A dispensing system was constructed to provide liquid nitrogen for the adsorber in the helium purification system and for the cold traps in the vacuum systems. The supply of liquid nitrogen is contained in two portable 200-liter Dewar flasks located in the corridor outside the facility. This system eliminates the need for moving liquid-nitrogen containers in and out of the facility and thus contributes to the overall program of control of contamination. Figure 11 is a schematic diagram of the system.

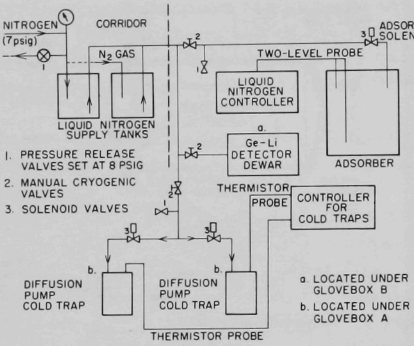


Fig. 11. Schematic Diagram of Liquid-nitrogen Dispensing System

The system uses gaseous nitrogen at 7 psig to force liquid nitrogen from the large Dewar flasks through vacuum-jacketed copper tubing to where it is used in the facility. The nitrogen passes through a distribution manifold, inside the laboratory, equipped with three manually operated cryogenic valves.[15]

The flow of liquid nitrogen to the purification system adsorber and to the cold traps is controlled by cryogenic solenoid-operated valves.[16] Thermistor sensing devices automatically detect the level of liquid nitrogen in each receptacle. A combination high- and low-level thermistor probe in the adsorber minimizes the number of filling operations and, thus, the loss of liquid nitrogen that occurs with each filling operation. Single-level probes are used in the vacuum cold traps, but time-delay relays prevent an excessive number of additions of liquid nitrogen.

The three cryogenic solenoid valves have switches that allow the automatic filling system to be overridden for manual filling of each receptacle. When the controllers for the liquid-nitrogen system are in the automatic mode of operation, neon bulbs on the control panel indicate when the liquid nitrogen is below the sensor levels and the valves are open. Pressure relief valves are connected to the liquid-nitrogen dispensing manifold between the manual and solenoid valves to protect against overpressure of the system.

2.2.1.5. Gloves. The gloveports in the helium section are equipped with two types of gloves. Rad Bar lead-loaded neoprene gloves[17] are used wherever equipment containing more than 1 g of plutonium must be handled directly with the gloves. These gloves contain a 30-mil layer of lead, which effectively attenuates the gamma radiation. The exterior of these gloves is made of Hypalon, which is very resistant to alpha radiation and chemical corrosion and has very low porosity to minimize helium diffusion. Rad Bar gloves are installed on both sides of the helium section in the furnace and weighing areas and next to the lower transfer port to the air section.

All the other gloves in the helium section and in the rest of the facility are Durasol neoprene gloves,[18] which have the same Hypalon exterior, but do not contain lead.

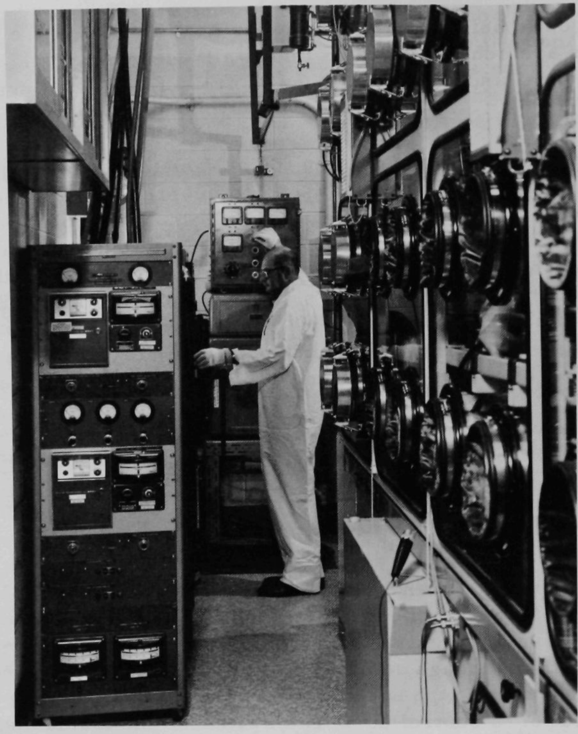
2.2.1.6. Utilities

2.2.1.6.1. Electrical. Standard 110-V power for fluorescent light fixtures,[19] balances, and other equipment is provided in the helium section at both ends of the section and at a central point adjacent to the furnace well. The power is provided either through standard three-wire outlets mounted in wire molds channels or through special connectors inside the glovebox. Each three-wire outlet is controlled by two switches, one inside and one outside the glovebox. Power supplied through the connectors is controlled by switches on the devices themselves or by intermediate control equipment.

The platinum-wound resistance furnace[20] is provided with controlled power up to 205 V and 20 A, and the three-zone furnace is provided with controlled power up to 110 V and 16 A.

Power to the tilting furnace, which is heated by an induction coil, is supplied by bus bars from a work station[21] in the operating area. The work station is powered by an industrial 15-kW, 10-kHz motor-generator[22] located in a basement area below the facility. The bus bars pass through the wall of the helium section containing the 19-in. vacuum bag port. The control panel and work station for the motor-generator are located in relay racks adjacent to the glovebox, as shown in Fig. 12.

Electrical power for the atmosphere control units and for one of the laboratory exhaust blowers (in the building fan loft) is connected to the emergency power system in the building to ensure that these units will continue to operate if the public-utility power fails.



308-1549

Fig. 12. Work Station and Controls for Induction-heated Tilting Furnace

2.2.1.6.2. Cooling-water System. Recirculating cooling water cools the flanges of the reactor tubes in the resistance-heated furnaces, the flanges on the tilting-furnace vessel, and the induction heating coil for the tilting furnace. The cooling-water system contains about 13 liters of water, which is cooled to 15-20°C by the heat exchanger of a commercial 2-ton water chiller.[23] Figure 13 is a view of the water chiller installed under the air section of glovebox A. Figure 14 is a schematic diagram of the cooling-water system. The chilled water is pumped by a centrifugal pump through the system to be cooled, to a sealed reservoir tank, and then back to the heat exchanger. Cooling water from this system is also distributed to the air section and to the analytical box.

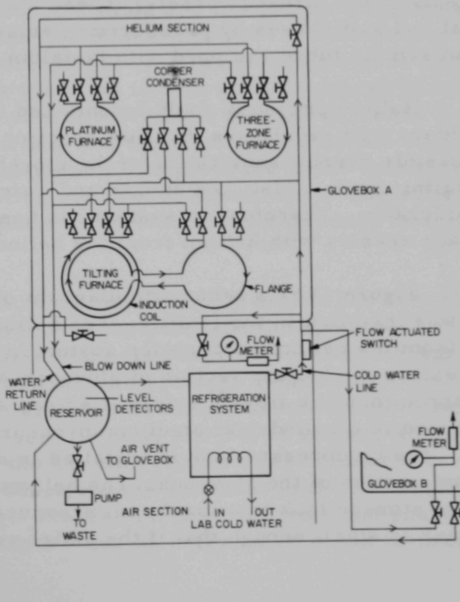
The inlet and return lines for each cooled unit in the helium section are equipped with a set of valves that can isolate the unit from the cooling system. At each valve there is an entry port that allows helium to be introduced to blow water from the unit back through a blowdown line to the reservoir. A vent line is provided from the reservoir to the air section to release the helium. With this system, any cooled unit can be disconnected from the cooling-water system without contaminating the dry-helium atmosphere with water.

308-1536

Fig. 13. Water Chiller for Recirculating Cooling-water System

Fig. 14

Schematic Diagram of Recirculating Cooling-water System



Several safety devices are installed in the cooling-water system to protect the equipment in the gloveboxes against loss of cooling or leakage. A flow-detection device[24] is present in the main cooling-water supply line between the chiller and the gloveboxes. If water is not flowing through this device, the furnace units that require cooling water within the helium section are rendered inoperable by an electrical interlock. If the circulating pump becomes inoperative, an alarm sounds.

The cooling-water reservoir is equipped with an electrical two-level detection device. When the entire cooling-water system and distribution lines are filled to the proper level (~13 liters), there is approximately 500 cc of water above the upper level detector. If the water level should fall below the upper level detector, a flashing warning light comes on. If about 1 liter of water is lost from the system and the lower level detector is reached, the circulating pump and chiller are rendered inoperable and an alarm sounds to inform the operators of the loss of cooling water.

In addition to the safety devices described above, the total volume of water in the system (~13 liters) is such that if all the water in the system were released into the helium section it would be contained as a shallow pool in the bottom of the glovebox, thus preventing the spread of any alpha activity outside the glovebox.

2.2.1.6.3. Pressurized Helium System. Various operations performed in the helium section require that helium pressure be exerted over the molten systems in the furnace vessels. These operations include sampling the metal and salt phases by pressurizing small amounts of the fluids into tantalum sample tubes equipped with tantalum filter frits.

Helium pressure could be obtained directly from standard helium cylinders with regulators, but this practice would be objectionable because of possible overpressurization of the glovebox in the event of a leak or operating error. Also, the oxygen and water content of tank helium varies considerably. Therefore, a system has been devised for pressurizing the furnace vessels with helium from the helium purification system.

Figure 15 is a schematic diagram of the pressurized helium system that was installed in the facility. The helium is withdrawn from the supply line from the helium purification system at a point just before the supply line enters the helium section of glovebox A. The helium passes through a 5-micron metallic filter[25] before it enters a diaphragm compressor[26] that is housed in a cylindrical steel compressor tank 14 in. in diameter by 20 in. high. The compressor tank is installed in an enclosed section beneath the helium section of the glovebox. The helium is then compressed in a 9-liter helium storage tank to a maximum pressure of 3250 mm. The volume of the tank is small enough that if the entire contents of the tank at 3250 mm

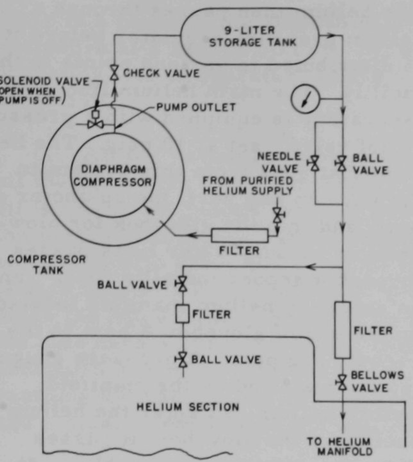


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Fig. 15. Schematic Diagram of Pressurized Helium System

pressure are discharged to the glovebox at one time, no noticeable change in glovebox pressure occurs. Pressure within the helium storage tank is monitored with a 0- to 4000-mm absolute-pressure gauge. Overpressure of the pump discharge line is prevented by a blowout device that is vented to the inlet side of the compressor within the compressor tank.

The compressed helium enters the helium section through two separate lines. A set of valves distributes the compressed helium to each line. The helium in each line passes through a metallic filter and another valve before entering the helium section. One line contains a 1- to 5-micron metallic filter,[27] and the other contains a 5-micron metallic filter.[25] The first line enters the helium section through the wall of the box; the second enters through the wall of the furnace well and connects to a helium manifold, which distributes the helium to the process equipment through solenoid valves.[28]

The pressure in the helium manifold and in equipment that may be open to the manifold can be measured with either a 0- to 4000-mm or a 0- to 2540-mm absolute-pressure gauge. The latter gauge can be read to an accuracy of 1 mm. The flow of helium in both entry lines can be controlled with either a ball valve or a needle valve, both of which are in the line between the helium storage tank and the point where the two supply lines branch from the main supply line. The pressure in the helium storage tank can be adjusted by controlling the flow of helium to the box. The helium flow is controlled by the needle valve while the compressor is running continuously.

2.2.1.6.4. Tank Helium. Standard cylinders supply helium for the helium purification system, the large vacuum bag port, and the sphincter can port, and for blowdown of cooling-water lines, as described earlier. Figure 16 is a schematic diagram of the tank helium system. Four helium cylinders, each equipped with a regulator, are located in the basement below the facility. Two of the regulators are set at 5 psig, and two at slightly above 7 psig. The manifold to which the helium cylinders are connected is equipped with a low-pressure sensor,[29] which sounds an alarm in the laboratory when the pressure falls below 7 psig. The helium from the manifold passes through a 50-micron metallic filter[30] and an entry valve in the laboratory.

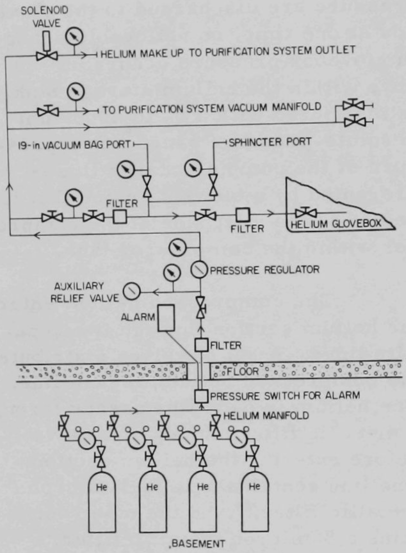


Fig. 16. Schematic Diagram of Tank Helium System

The helium then passes through a helium pressure regulator before it is distributed to various points in the facility. The main helium line in the laboratory is equipped with a pressure relief valve[31] set at 10 psig. The helium that goes from this system to the vacuum bag port, the sphincter can port, and into the glovebox for blowdown of cooling-water lines passes through a second metallic filter[30] and an auxiliary helium manifold located on the end of glovebox A next to the vacuum bag port. A pressure gauge is also installed on the manifold. Before helium can enter the helium section of the glovebox, it passes through a valve, a removable 1- to 5-micron filter,[27] and another valve located inside the glovebox. With all valves wide open, the helium flow into the helium section is very slow and is easily handled by the atmosphere control system.

2.2.1.7. Vacuum Systems and Subbox Enclosure. Three independent vacuum systems are used in conjunction with the helium section of glovebox A. One system, the port vacuum system, is used to evacuate all the entry ports to the helium section. The other two systems, the process vacuum systems, are used to apply vacuum to the experimental equipment located in the helium section. Five mechanical vacuum pumps are used with the three systems, and all five pumps discharge their exhaust gases into a common line made of copper pipe. The copper pipe is connected to a large filter[32] that removes oil from the gases. The gases leaving the filter are passed through a duct to a filter and blower system in the building fan loft.

All the vacuum pumps are located in an enclosed space under the helium section of glovebox A, referred to as the subbox enclosure. The pumps are protected from radioactive material in the glovebox and ports by filters installed in the vacuum lines. However, there is a possibility that small amounts of radioactive material will enter the subbox enclosure. Therefore, the enclosure is treated as an active area.

Although the subbox enclosure is not completely sealed, it is kept at a negative pressure (-0.3 in. H_2O) relative to the room pressure. The enclosure is connected to the filters and blowers in the building fan loft through an AEC-type absolute filter having an area of 1 sq ft. An identical filter in a panel of the enclosure allows air to enter and pass through the enclosure at a rate of 50 cfm. When all the pumps in the enclosure are operating, the temperature of the enclosure near the exhaust filter is about 39°C.

All the vacuum pumps in the enclosure rest in pans to confine any oil that may leak from the pumps. Metal mirrors are provided to view the oil levels in the pumps through windows in the panels of the enclosure. All the mechanical pumps can be drained through copper lines into an evacuated steel tank with sufficient capacity for several years of operation. When the tank is full, it will be detached, capped, and discarded as active waste. Since the equipment must occasionally be serviced within the enclosure, the side panels are removable. When one of these panels is removed, the precautions used in entering any alpha enclosure are observed. These precautions include the use of respirators, protective clothing, floor coverings, and a plastic tent around the opening.

2.2.1.7.1. Port Vacuum System. A large mechanical vacuum pump[33] is used to evacuate all the entry ports to the helium section. The evacuated air or helium (helium is sometimes used to flush the ports before final evacuation) passes through 0.3-micron filters[34] and through vibration eliminators placed in the lines between the ports and the vacuum pump.

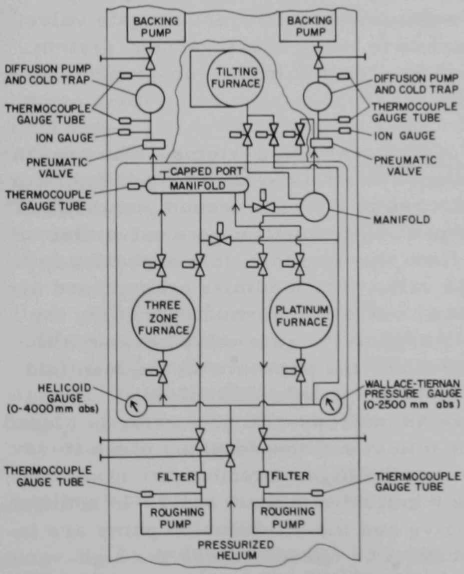


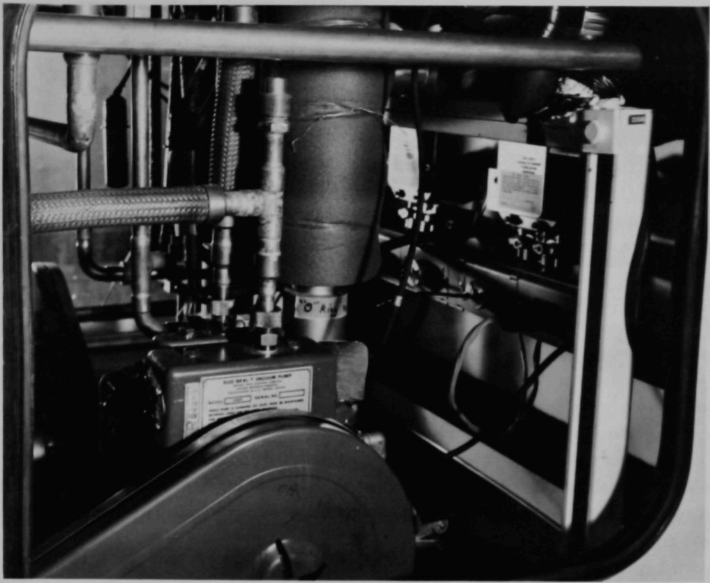
Fig. 17. Schematic Diagram of Process Vacuum Systems

2.2.1.7.2. Process Vacuum Systems. Two separate process vacuum systems are used in the helium section of glovebox A. One vacuum system is used for both the three-zone and the platinum-wound furnace; the other is used with the tilting furnace. The process vacuum systems are employed to evacuate equipment for experiments conducted under a vacuum or helium atmosphere. The following subsections discuss the components of the vacuum systems, and Fig. 17 is a schematic diagram of the systems.

2.2.1.7.2.1. Manifolds and Roughing Pumps. A separate vacuum manifold and roughing pump are used with each process vacuum system. The manifolds, constructed of 2-in. Schedule 10 Type 304 stainless steel pipe, are connected to the process equipment by 3/4-in. copper tubing, O-ring vacuum compression fittings, and 3/4-in. solenoid vacuum valves. The manifolds are each connected to Welch Duo Seal mechanical roughing pumps[35] through 3/4-in. solenoid vacuum valves, 3/4-in. copper tubing, vibration eliminators, 0.3-micron filters,[34] and 3/4-in. hand-operated valves. A Veeco thermistor-type thermocouple gauge tube[36] is attached to each manifold for vacuum measurement. The manifold for the three-zone and platinum-wound furnaces is located in the furnace-well portion of the helium section; the manifold for the tilting furnace originates in the furnace well and extends above the floor of the glovebox near the tilting furnace. Both vacuum manifolds pass through welded couplings in the furnace well into the subbox enclosure, where they are connected by O-ring flanges to the high-vacuum systems described in the next subsection.

2.2.1.7.2.2. <u>High-vacuum Systems</u>. Each process vacuum system has a separate high-vacuum system capable of evacuating the vacuum manifolds and any process apparatus connected to the manifolds to a pressure of 10^{-6} Torr. Each high-vacuum system (see Fig. 17) has the following components, proceeding toward the vacuum manifolds: a Welch Duo Seal mechanical backing pump,[37] a vibration eliminator, a hand-operated vacuum valve, a thermistor-type thermocouple gauge tube,[36] a 2-in.-diam water-cooled oil diffusion pump,[38] a 2-in.-diam liquid-nitrogen-cooled cold trap,[39] a cold-cathode ion gauge tube,[40] another thermistor-type thermocouple gauge tube,[36] and a 2-in. pneumatic solenoid-actuated vacuum gate valve.[41] A 2-in. line from the gate valve attaches to the process vacuum system manifold. Both high-vacuum systems are located in the subbox enclosure; portions of one are shown in Fig. 18.

2.2.1.7.2.3. <u>Operation and Control of High-vacuum Systems.</u> The pressure in the manifold of each process vacuum system is sensed by a thermistor-type thermocouple tube, which is attached to a Veeco vacuum controller.[42] The vacuum controller operates the pneumatic vacuum gate valve that separates the high-vacuum system from the manifold; this operation is accomplished by actuating a solenoid valve, which admits pressurized air to the operating piston of the pneumatic valve. In normal operation, the thermocouple gauge controller is set to open the gate valve between the manifold and the high-vacuum system when the pressure in the manifold or in any apparatus open to the manifold drops below 40 microns. When the pressure in the manifold is above 40 microns, the gate valve is closed and the solenoid valve between the manifold and the roughing pump is opened. The system is designed so that the high-vacuum system and the roughing pump cannot be open to the manifold simultaneously. In addition, the power supplies to the solenoid valve and the oil diffusion pump are interconnected so that the gate valve cannot be opened unless the high-vacuum system is operating. All the interlocks in the system are automatically reversible; thus, components that have been isolated or rendered inoperable are reactivated when conditions in related systems return to normal.



308-1539

Fig. 18. High-vacuum System

The pressure in the high-vacuum system is monitored by a thermocouple gauge and a cold-cathode ion gauge between the gate valve and the cold trap. These gauges are connected to a Veeco high-vacuum controller,[43] which controls the power to the oil-diffusion-pump heater. When the thermocouple gauge reads below 100 microns, the diffusion pump is turned on. The ion gauge monitors the high-vacuum condition of the system and is turned on automatically when the thermocouple gauge reads below 10 microns.

The diffusion-pump heater is also connected electrically to a bellows-type differential pressure sensor,[44] which is set up to measure cooling-water flow to the diffusion pump. If the water flow drops below the desired level, the diffusion pump is automatically shut down. Therefore, in order for the gate valve to open the high-vacuum system to the process vacuum manifold and connected apparatus, the diffusion pump must be operating, and operation of the diffusion pump is dependent on sufficient cooling water and proper backing pump pressure.

The vacuum gate valve is operated by air pressure in the 50- to 100-psig range from the building high-pressure air supply. The air from the building supply line passes through a manually operated valve, a flow-limiting orifice, and a 9-liter reservoir tank before reaching the solenoid valve that controls the pneumatically operated vacuum gate valve. The pressure in the reservoir is maintained at 50-100 psig by a constant but slow bleed of air through the orifice from the building air supply. The rate of flow to the tank is low enough and the volume of the tank is small enough that any leak or sudden release of air to the subbox enclosure from the valve-operating air could be handled by the exhaust system for the enclosure. The 9-liter tank is equipped with a sensor-gauge[45] that will sound an alarm if pressure in the tank falls below the 50 psig minimum required to operate the gate valve.

The control panel for all the vacuum systems is located on the lower side of glovebox A below the weighing section. Part of the panel can be seen in the lower portion of Fig. 6. The process vacuum system is displayed on the panel in schematic form. The solenoid and pneumatic valves described above can be operated manually or automatically with switches located on the control panel. Pilot lights on the panel show whether the valves in the system are open or closed. Similar controls and lights are provided for the diffusion-pump heaters, roughing pumps, backing pumps, and the port vacuum pump. The vacuum controllers and gauges mentioned above are also mounted on this panel along with a vacuum thermocouple gauge switch and a vacuum thermocouple gauge, which are used to monitor vacuum at other points in the systems.

All the mechanical vacuum pumps that can be connected to the interior of the helium section or helium purification system are interlocked to a system that shuts the pumps down automatically if the pressure in the box drops below 4 in. of H_2O less than that in the surrounding room. A reset button must be pressed to restart the pumps after they have been shut down by this system.

2.2.1.8. Furnaces and Furnace Vessels. The helium section of glovebox A contains three furnaces. Two of the furnaces (a platinum-wound furnace and a three-zone furnace) are mounted in the furnace well below the floor of the box. The furnace well extends into the subbox enclosure so that the air flow through the enclosure cools the walls of the well. The third furnace (a tilting furnace) is installed above the box floor level near the weighing section of the box. All furnaces are equipped with thermostatic switches on their flanges that will shut off the power to the furnaces if the temperature of their flanges rises above 50°C.

2.2.1.8.1. Three-zone Furnace. The three-zone furnace[46] contains a Type 304 stainless steel furnace vessel $2\frac{3}{4}$ in. in diameter by $19\frac{1}{4}$ in. deep and is capable of temperatures up to about 1200°C. The vessel contains a 30-mil tantalum liner, which extends to within 1/16 in. of the furnace top. The furnace is controlled by a proportioning controller.[47] Several heads were made for the three-zone furnace tube for various uses. Figure 19

308-1531

Fig. 19. Operator Closing Three-zone Furnace

shows an operator installing a head containing a central thermocouple well, which was used to obtain a temperature profile within the furnace. The three-zone furnace is used for any work requiring that an isothermal zone be maintained in the area surrounding the reacting components. This furnace can be used for reducing metal oxides in metal-salt systems, equilibrating metal-salt systems and alloys, and preparing alloys and salt mixtures.

2.2.1.8.2. Platinum-wound Furnace. The platinum-wound (platinum-rhodium) furnace[20] is capable of temperatures up to 1500°C. The furnace is controlled by a controller similar to the one used with the three-zone furnace. The furnace vessel for the platinum-wound furnace was machined from a solid bar of Type 310 stainless steel to provide good strength at high operating temperatures. The vessel is $1\frac{7}{8}$ in. in diameter by $23\frac{1}{4}$ in. deep and contains a tantalum liner.

Although the platinum-wound furnace can be used for purposes similar to those of the three-zone furnace, its principal use is for retorting, that is, the separation of volatile alloy constituents such as magnesium, zinc, and cadmium from plutonium, which is left as a residue in the retorting vessel. The volatilized constituents of the alloys are collected on a water-cooled copper cold finger mounted on a furnace vessel head.

2.2.1.8.3. Induction-heated Tilting Furnace. The induction-heated tilting furnace (shown in Fig. 20) is used to reduce metal oxides of plutonium with molten metal-salt systems and to conduct experiments in which a molten salt is contacted alternately with two different metal alloys. The furnace, constructed of two pieces of 4-in.-ID Type 304 stainless steel pipe, can operate at temperatures up to about 1000°C. The furnace will accommodate crucibles and pouring molds up to 6 in. deep. A dual-compartment tantalum crucible is used in the salt-metal contacting in experiments. The furnace is tipped to allow the molten salt to pour from one compartment of the dual crucible to the other to provide contact with the different metal alloys. The furnace is also equipped with a side neck, which allows melts to be poured into a receiver at the end of an experiment.

308-1537

Fig. 20. Induction-heated Tilting Furnace

The tilting mechanism of the furnace uses an induction motor[48] with a gear reducer and an adjustable-torque slip clutch. Adjustable stops are placed to limit the angle of tilting. The tilting motor is controlled by a switch outside the glovebox.

The furnace is heated with an induction coil that is powered by a motor-generator unit (described in Section 2.2.1.6.1). The induction coil is cooled by the recirculating refrigerated-water system. Temperature is controlled by a proportioning controller.[47] The furnace head is equipped with two sample ports and two agitators, which are driven by variable-speed induction motors.[49] Thus, when the dual-compartment crucible is used, both compartments can be agitated and sampled independently.

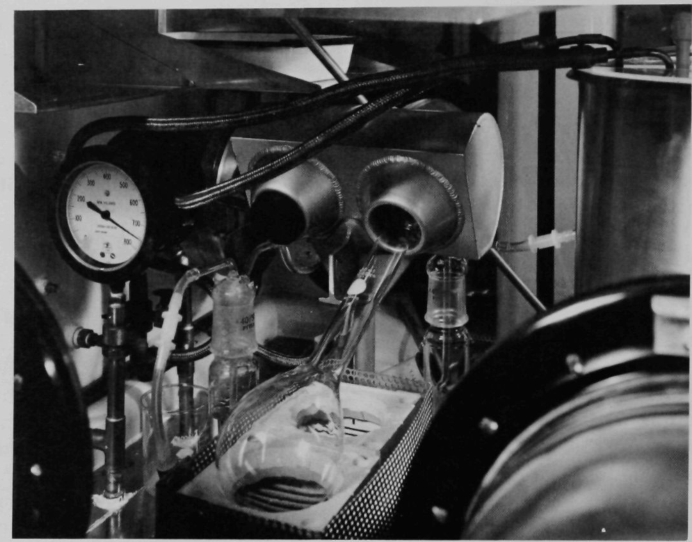
2.2.1.8.4. Temperature Measurement. Temperatures in the processing vessels and furnaces are sensed by Chromel-Alumel and platinum-rhodium thermocouples. The outputs of some of the thermocouples are recorded on two recorders.[50,51] The temperatures at other locations in the glovebox, furnace well, and subbox enclosure are monitored with a dial-type indicator.[52] When all three furnaces are operating in the helium section of the glovebox, all the temperatures observed inside the glovebox are within safe limits.

2.2.2. Air Section

The air section of glovebox A is used primarily for dissolution of metal, oxide, and salt samples obtained from the experimental work performed in the helium section. The air section is also used as an intermediate area for the transfer of items into the helium section from outside the glovebox and for movement of items between the helium section and glovebox B via the transfer tunnel. The materials-handling and radiation safeguards used in the air section are similar to those employed in the helium section. The quantities of plutonium-238 handled in individual operations such as sample dissolution, solvent extraction, volume reduction, and ion exchange are generally less than 1 g. Small amounts of solutions, 25-100 cm^3, containing low concentrations ($\sim 1\ mg/cm^3$) of plutonium are stored temporarily in the air section. Figure 21 shows some of the equipment in the air section that is used for sample dissolution, including a fume duct, an aspirator pump, and wash bottles used to control fumes within the air section.

2.2.2.1. Atmosphere Control. Air enters one end of the air section through an AEC-type absolute filter with an area of 1 sq ft. The air is distributed through channels in the bottom of the glovebox and is exhausted from the upper portion of the glovebox through two parallel filter banks, each containing two filters in series. Each of the four exhaust filters is identical to the inlet filter. The exhausted air goes through a duct and into the fan loft, where it is filtered again before it passes through the blowers and is discharged outside the building. Two blowers are used in the fan loft, one of which is connected to the building's emergency power generator to ensure that the pressure in the gloveboxes can be maintained below atmospheric pressure in the event of a power failure.

A stainless steel hood is provided inside the air section to control corrosive fumes arising from the dissolution of samples. The hood is connected by a flexible steel duct to one of the exhaust-filter chambers used to exhaust the air from the air section. The release of corrosive fumes that would vent to the hood is minimized by using chemical traps and a recirculating aspirator pump between the hood and any apparatus evolving corrosive fumes.



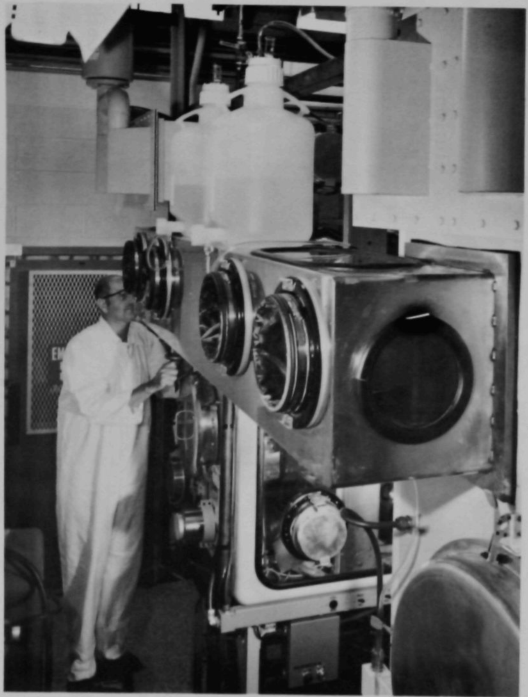
308-1534

Fig. 21. Air Section of Glovebox A

2.2.2.2. Entry and Egress from Air Section. Items can be introduced into and removed from the air section through a $7\frac{1}{2}$- and 15-in. bag port located at the end of the glovebox opposite the 19-in. vacuum bag port. A 4-in.-diam sphincter port is also provided for one-way introduction of small items to the air section. (The use of two vacuum ports for transferring materials between the air and helium sections was discussed in Section 2.2.1.3.)

Materials are transferred between the air section of glovebox A and glovebox B through a transfer tunnel that extends between the upper ends of the two gloveboxes. The transfer tunnel (shown in Fig. 22) is 14 in. high by 12 in. wide and is equipped with windows and gloves for observing and manipulating materials inside the tunnel. The tunnel contains a movable tray, which is actuated by a sealed crank drive located at the bottom of the tunnel at the end connected to glovebox A. Figure 23 is a view of the interior of the transfer tunnel; a plastic reagent jar is shown on the movable tray.

2.2.2.3. Elevators and Storage Shelves. Three motor-driven, vertical-screw elevators are provided in the gloveboxes (one in the air section of glovebox A and two in the analytical glovebox) to raise and lower items



308-1535

Fig. 22. Exterior View of Transfer Tunnel

308-1548

Fig. 23. Interior View of Transfer Tunnel

from the floor of the gloveboxes to storage shelves and to the transfer-tunnel doors. Figure 24 shows an operator moving a reagent bottle from an elevator tray and placing it on the transfer-tunnel tray.

308-1541

Fig. 24. Transfer of Materials from Elevator to Transfer Tunnel

Adjustable stainless steel storage shelves are located along the wall in the end of the air section near the transfer-tunnel door. The shelves are used to store reagents and aqueous solutions containing plutonium-238. The quantity of plutonium-238 stored in aqueous solutions is limited to that necessary for analytical purposes. The solutions are stored in primary containers, which are vented to allow for gases evolved from decomposition caused by radiation. Secondary metal containers are used for storage of all liquid solutions.

2.2.2.4. Utilities

2.2.2.4.1. Electrical. Standard 110-V power is distributed through standard three-wire outlets mounted in wire mold channels on the inside of the air section at the end containing the bag ports. The control and use of this power are similar to that in the helium section. The 110-V power supplied to the elevator is controlled by a switch on the exterior of the glovebox.

2.2.2.4.2. Cooling Water. Recirculated cooling water is supplied to both the air and helium sections of glovebox A from the same system; the water lines are introduced into the air section through fittings in the wall dividing the air and helium sections. In the air section, cooling is needed for the solution in the recirculating aspirator system, which is heated by its recirculation pump.

2.2.2.4.3. Helium or Low-pressure Air Inlet. An inlet has been provided in the wall containing the bag ports for the introduction of either helium or low-pressure air. The inlet consists of a quick-disconnect gas connection, a valve, and a 3/4-in. 1 to 5-micron filter on the outside of the box, and a quick-disconnect gas connection on the inside of the box.

2.2.2.4.4. Distilled Water. Distilled water is supplied from a plastic container[53] mounted above the transfer tunnel (as shown in Fig. 22) to a fitting penetrating the wall of the glovebox that contains the bag ports.

2.3. Glovebox B

Glovebox B (shown in Fig. 25) has an air atmosphere and serves as an analytical facility for the experimental work performed in glovebox A. Most of the plutonium-238 contained in the analytical glovebox is in aqueous solution, and the total amount of plutonium-238 in the glovebox is limited to less than 1 g. Solutions transferred through the transfer tunnel into the

308-1543

Fig. 25. Glovebox B

analytical glovebox from the air section of glovebox A are assayed for plutonium-238 with a lithium-drifted germanium diode detector[54] located below the floor of the glovebox. Figure 26 shows an operator placing a sample into a well in the floor of the glovebox above the detector.

308-1542

Fig. 26. Counting Well

2.3.1. Atmosphere Control

The atmosphere control for the analytical glovebox is identical to that described for the air section of glovebox A. Under normal operating conditions, the door to the transfer tunnel in the analytical glovebox is kept open to maintain a negative pressure in the transfer tunnel.

2.3.2. Entry and Egress from Glovebox B

Items can be introduced into and removed from the analytical glovebox through a $21\frac{1}{2}$- and $7\frac{1}{2}$-in. bag port located at one end of the glovebox. Figure 27 shows operators using a bag sealer[55] to seal an item that has been transferred out

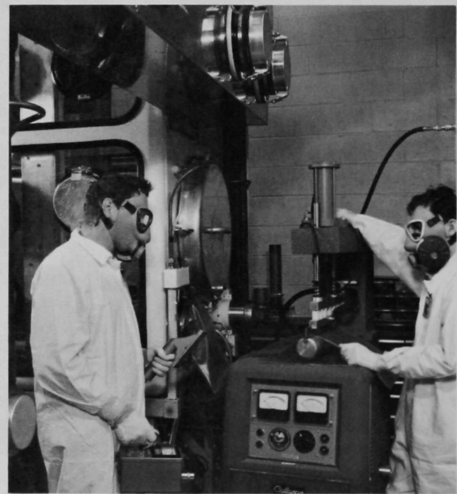


Fig. 27

Bagging Operation

308-1552

through the smaller bag port of the glovebox. Two 4-in.-diam sphincter ports are available, one at each end of the analytical glovebox, for the rapid introduction of small items to the glovebox. (Entry to the analytical glovebox through the transfer tunnel from the air section of glovebox A was discussed previously in Section 2.2.2.2.)

2.3.3. Utilities

The utilities provided in glovebox B, including electrical, cooling water, distilled water, and helium or low-pressure air inlet, are the same as those provided in the air section of glovebox A.

2.3.4. Activity-free Section

A portion of one corner of the analytical glovebox, 20 by 40 by 20 in. high, has been sealed off from the rest of the glovebox. This portion, referred to as the activity-free section, is treated as being outside the alpha-active section and is used to transfer samples out of the analytical glovebox to other analytical facilities. Air from outside the glovebox is drawn from two open gloveports in the activity-free section and into the main part of the analytical glovebox through a 6-in.-square AEC-type absolute filter. When the gloveports are not being used, they are closed with covers that allow air to be drawn into the activity-free section.

Before any sample solution is introduced to the activity-free section of glovebox B, it is assayed for plutonium-238 content with the lithium-drifted germanium diode detector using the 99- and 153-keV characteristic gamma rays. If the quantity of plutonium-238 in the sample is low enough (<50 μg), the sample can then be transferred to the activity-free section for subsequent transfer to a plutonium-239 analytical laboratory outside the facility.

308-1545

Fig. 28. Activity-free Section of Glovebox B

Solutions are transferred into the activity-free section by pipetting the solution into a container in the activity-free section through a compression fitting in the top surface of the section. (This operation is demonstrated in Fig. 28.) The compression fitting is mounted in a plastic retaining ring sealed into an opening in the glass plate that serves as the top for the activity-free section.

3. OPERATING EXPERIENCE

The facility has been used to conduct experiments with plutonium-238 from the middle of 1968 to the present. (The experimental work and results will be described in a later publication.) All the equipment in the facility has been used successfully and has performed according to design specifications. The water and oxygen concentrations in the helium atmosphere section have been maintained at less than 2 and 5 ppm, respectively, during the experimental work.

All alpha activity has been confined to the interior of the gloveboxes, and radiation exposure of operating personnel has been well below allowed safe limits.

ACKNOWLEDGMENTS

The author wishes to acknowledge the efforts of others who made valuable contributions to the design and construction of the facility. John O. Ludlow provided suggestions in the early stages of design of the facility and developed the helium purification system. Michael A. Slawecki contributed to the design and supervised the installation of the electrical equipment. Harry O. Smith provided the necessary design drafting work for the project, and Herbert L. Brown supervised and coordinated its installation. William E. Miller provided assistance in the design of the processing equipment, and Robert P. Larsen helped with the design of the analytical portion of the facility. John J. Heiberger, John D. Schilb, and James R. Haley provided valuable technical assistance in the overall development and construction of the facility.

APPENDIX

Items Used in Construction of Plutonium-238 Research and Development Facility

Item No.	Description	Supplier or Manufacturer	Model
1	Neutron dosimeter	Texas Nuclear c/o Nuclear Chicago Des Plaines, Ill.	9141
2	Air monitor, solid state	Radiation Detecting Equipment Pleasant Hill, Calif.	RAD 221A
3	Lathe	Allied Electronics Chicago, Ill.	Unimat 26D143U
4	Laboratory grinder	Crescent Dental Mfg. Chicago, Ill.	Wig-L-Bug No. 6
5	3-kg torsion balance	E. H. Sargent Chicago, Ill.	Mettler P-3
6	120-g torsion balance	A. Daigger Co. Chicago, Ill.	Torbal DLT-2
7	Analytical balance	LaPine Scientific Chicago, Ill.	Torbal EA-1
8	Rotary storage bin, metal	General Industrial Chicago, Ill.	RB-1708
9	Oxygen analyzer	Meeco Warrington, Pa.	O
10	Water analyzer	Meeco Warrington, Pa.	W
11	Hygrometer	Panametrics Berkeley, Ill.	1000
12	Oxygen analyzer	Thermo-Lab Instruments Pittsburg, Pa.	Thermox
13	Differential pressure gauge	Dwyer Controls Michigan City, Ind.	2004
14	Differential pressure sensor	Dwyer Controls Michigan City, Ind.	1627-1 1627-2
15	Cryogenic valves	Lesman Instrument Berkeley, Ill.	Worcester 1/4-4-1-1 T-TE

Item No.	Description	Supplier or Manufacturer	Model
16	Cryogenic solenoid valve	Smith & Machay Atkomatic Valve Co. Chicago, Ill.	BDGS
17	Lead-loaded gloves	Charleston Rubber Co. Charleston, S.C.	8NLY-3032
18	Dry box gloves	Charleston Rubber Co. Charleston, S.C.	8NY-3032
19	Fluorescent tubes	Wilco, Inc. Wichita, Kans.	DRV 15-GK3
20	Furnace, Pt-20% Rh	Marshall Products Columbus, Ohio	1353
21	Work station	Ohio Crank-shaft Cleveland, Ohio	Tocco 1RS2
22	Induction generator	Ohio Crank-shaft Cleveland, Ohio	Tocco 1Mg-15-1
23	Water chiller	Acme Industries Jackson, Mich.	SPW-2
24	Flow-detection sensor	Hays Mfg. Erie, Penn.	Series 2600
25	Filter, 5-micron	Haddam Mfg. Haddam, Conn.	2012-75-6
26	Diaphragm compressor	Bachll Paint Company Chicago, Ill.	NCE-501
27	Metallic Filter	Hoke-Enpro Maywood, Ill.	6357-G4B
28	Solenoid valve	Vacuum Electronics Chicago, Ill.	SU62S
29	Pressure sensor	Allen-Bradley Revere Electric Chicago, Ill.	Bulletin 836
30	Metallic filter, 50-micron	Norgren Littleton, Colo.	30Be N3-50
31	Pressure relief valve	Rego Chicago, Ill.	2866
32	Filter in vacuum exhaust	Enpro Incorporated Villa Park, Ill.	Pall MDC 1003 SU-24H-Z3

Item No.	Description	Supplier or Manufacturer	Model
33	Vacuum pump	E. H. Sargent Chicago, Ill.	Welch 1397C
34	Filter, 0.3-micron	Enpro Incorporated Villa Park, Ill.	MCS- 1001-SU
35	Vacuum pump	E. H. Sargent Chicago, Ill.	Welch 1402
36	Thermistor thermocouple gauge tube	Vacuum Electronics Chicago, Ill.	DV-1M
37	Vacuum pump	E. H. Sargent Chicago, Ill.	Welch 1405
38	Oil diffusion pump	Vacuum Electronics Chicago, Ill.	EP-2W
39	Cold traps	Vacuum Electronics Chicago, Ill.	CT-200
40	Cold-cathode ion gauge tube	Vacuum Electronics Chicago, Ill.	DG-2-1
41	Pneumatic valve	Vacuum Research Chicago, Ill.	VRC 2TIEPLS
42	Vacuum controller	Vacuum Electronics Chicago, Ill.	TC-9
43	Vacuum controller	Vacuum Electronics Chicago, Ill.	TC-DG-9
44	Differential pressure sensor	United Electric Controls Chicago, Ill.	J21K- 9532
45	Pressure alarm gauge	Affiliated Steam Equip. Chicago, Ill.	Cat. No. 1379A
46	Furnace, 3-zone	Marshall Products Columbus, Ohio	Custom
	Furnace controller	Ray Welch Instruments Hammond, Ind.	West JYSCR-2 Type K
	Controller power supply	Ray Welch Instruments Hammond, Ind.	PSCR-15-120
48	Induction motor	Chicago Bearing & Power Drive Co. Chicago, Ill.	P-3P

Item No.	Description	Supplier or Manufacturer	Model
49	Induction stirring motor	Gaylord Rives Co. Pasadena, Calif.	BH-556
50	Recorder, multipoint	Honeywell Minneapolis, Minn.	Brown Electronik
51	Recorder, AZAR	Leads and Northrup Park Ridge, Ill.	Speedomax W
52	Temperature indicator	Honeywell Minneapolis, Minn.	0-250°C
53	Polyethylene container	LaPine Scientific Chicago, Ill.	2318-3
54	Germanium-lithium diode detector	Nuclear Diodes Chicago, Ill.	LGC-2.5
55	Bag sealer	J. A. Callanan Company Chicago, Ill.	40

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